Drag Coefficient Distribution and Wind Speed Dependence in Tropical Cyclones

Year 2 Mid-term Progress Report to the Joint Hurricane Testbed

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Project Abstract

This project will update the most recent measurements of surface drag coefficient (Cd) in hurricanes to extend the measurements to mean boundary layer (MBL) winds over 70 m/s. All available GPS sonde profiles collected in hurricanes from 1997-2004 will be processed, stored in a modern relational database, quality controlled, and organized by mean boundary layer wind speed, storm relative location, and water depth. Profiles will be averaged and analyzed to provide updated values of surface stress, roughness, and Cd as a function of wind speed, storm-relative azimuth, and water depth. These mean profiles and associated derived surface exchange quantities will be made available to modelers to evaluate existing model surface layer momentum flux packages as well as develop new relationships for the coupled H-WRF model. The proposed effort is applied towards numerical weather prediction priorities EMC-1 and EMC-2.

A. Progress Report:

During the first half of the second year of the project we have focused on the sonde inventory, and cross-indexing the sonde database with flight-level data.

1. An inventory was assembled to allow the investigators to determine how many sondes have been launched for each research or recon flight, how many were transmitted, and how many were post processed. As of 10-06-2006, the inventory contains 6110 sondes that have been launched since 1997. This is an increase from 4368 sondes that were in our last report in March 2006.

2. Post-processed sondes files have been assembled and we are in the process of loading them into the database. So far, 2249 sonde files have been loaded into the database (a 520 sonde increase from 1729 profiles reported in March 2006). Many of these sondes, after post processing, do not contain information about what storm they have been dropped into only flight information. After associating a sonde with a particular flight using operator logs, we must also link the flight to a storm. This process can be encumbered if more than one storm is active and if more

than one flight is taking place during the same day. In such a case comparing a sonde's latitude and longitude to the storm's position is needed to accurately link a sonde to a storm.

3. From a total of 42 tropical cyclones since 1997, 443 storm track files (an increase from 194 in our April 2006 report) have been constructed using wind center fixes from the 550 flights in the inventory**.** The track files allow spline fits to the change in storm latitude and longitude with time, allowing calculation of the storm-relative radial and azimuthal coordinates of the sonde splash locations as well as the radial and tangential wind components. Sondes dropped during NOAA G-4 flights are also contained in the database and must use storm track files created from other flights that took place during the time of a G-4 flight.

4. One of the more time consuming aspects of the project is to integrate a database of flight-level observations organized by radial flight legs. The scaled radial coordinate will be determined by using the maximum flight-level wind speed on the particular radial leg on which a sonde has been launched. Sondes launched on non-radial legs could be assigned a scaled radial coordinate based on azimuthal proximity to to radial flight legs. We have been ingesting the flight-level data into the database (Airforce C-130s, NOAA P3's) and less than 10% of the flight level data for the 2005 season remain to be loaded. Once this is complete we will have flight level data from 1997-2005 in the database.

5. Out of the 2249 sonde files loaded into the database as of 10-16-2006, the data are distributed by mean boundary layer (MBL) wind speed as follows:

Table 1 Number of sonde profiles as a function of MBL wind speed group.

MBL group (m/s)	Sonde profiles in database (3-20-2006)	Sonde profiles in database (10-16-2006)
< 20		842
20-29	226	359
30-39	294	331
40-49	255	276
50-59	162	181
60-69	123	133
70-79	94	100

80-89	26	27

So far, with about a half of the database loaded, the 20-29 m/s through 50-59 m/s MBL groups meet the target of > 150 profiles needed to investigate azimuthal differences in the boundary layer and surface layer wind profiles. In addition, there are sufficient profiles (100) to examine the mean profile for the 70-79 m/s MBL group. This group did not contain sufficient samples to construct a profile in the Powell et al., 2003 study.

B. Hardware / software:

No purchases are needed at present.

C. Remaining work

1. Quality Control

Metadata files have been examined to look for gross errors in the storm relative position and flow calculations, and the derived quantities have been computed using routines developed by Matt Easton. During QC, errors in storm tracks were found for about 10% of the sondes and these are being investigated. The errors are probably caused by identifying a sonde with another storm on the same date.

Sonde data are binned to provide relatively high vertical resolution near the surface and then lower resolution above the boundary layer. Height bins are identical to those chosen for the Nature paper with 4 m bins near the surface (8-12, 13-16,17-20), ten m bins through the surface layer to 300 m (21-30, 31-40), 20 m bins through 500 m (e.g. 301-320, 501-550), 50 m bins through 1000 m, and 100 m bins above 1000 m. The standard error of the bin averaged mean wind values (ratio of the standard deviation to the square root of the number of samples) is computed for each bin as an indicator of bins with poor estimates of the mean wind speed. Based on preliminary analysis with 1017 profiles we will remove from consideration all bins with < 10 wind samples and/or standard errors > 1.0 m/s. This tends to happen at bins in the lowest 50 m when examining the high wind MBL groups, especially after dividing into azimuth or radial categories within an MBL group. When the database loading through the 2005 season is completed, we will have several hundred more profiles available for analysis so our bin mean estimates should improve due to a larger sample size. Further criteria to be considered in the analysis include the number of satellites used in the wind calculation and wind processing flags.

2. Drag coefficient behavior

One of the main interests of this project is to investigate the azimuthal dependence of the drag coefficient. As depicted by this plot from Wright et al and Ed Walsh's scanning radar altimeter wave data (Fig. 1) superimposed on an H*Wind analysis of Hurricane Bonnie of 1998, we can divide the storm into three regions: 1) Left front where the swell travels across the wind, 2) Right side where swell and winds coincide, and 3) left rear where the sea is more confused and at times has winds going against the waves. Preliminary results shown at the 2006 IHC showed a dependence on radial distance and low sensitivity to azimuthal position. Analysis will be repeated with the larger database that includes sondes processed up through the end of October 2006 (the cut-off data for the final dataset). We will also examine sensitivity to inertial stability and relative angular momentum in light of recent modeling results by Kepert (2006).

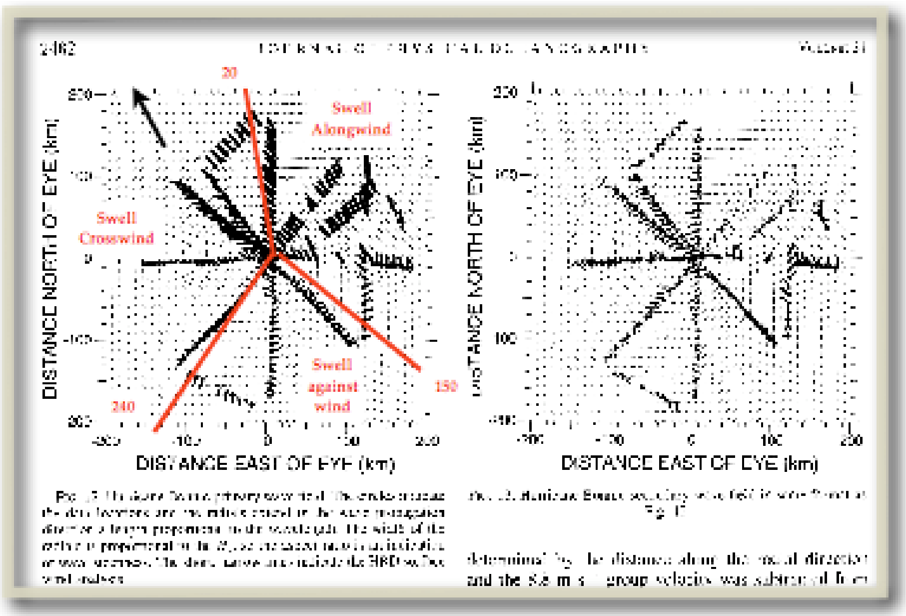

Figure 1. from Wright et al., 2001 showing wave and wind field for Hurricane Bonnie.

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